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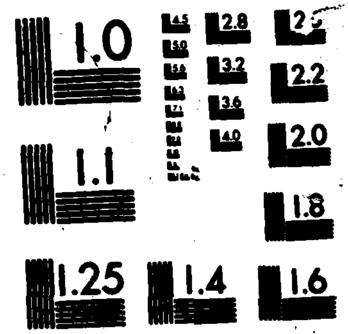

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NAVFAC BURIAL SYSTEM FOR
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NAVFAC BURIAL SYSTEM FOR UNDERWATER CABLES AND PIPES

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REVIEW AND ASSESSMENT OF PERFORMANCE REQUIREMENTS

AS LISTED IN THE STATEMENT OF WORK

1976

Opening Remarks

It is understood that the aim of the project is to acquire a system for laying and burying cables and small pipes so as to provide protection against dragging anchors, trawl boards, moving ice, and similar hazards. However, the statement of work bears the title "Procurement Specification for Underwater Trencher", and there are repeated references to requirements for a trencher. At present, the chief method of burying subsea pipe is jetting, and the chief method of burying submarine cables is plowing; neither method requires a machine that would properly be described as a trencher. It might be advisable to say whether the requirement is for a burial system, a trencher, or some sort of combination.

The system is expected to perform in both soft and hard bottom materials. It has to rely on "state-of-the-art" equipment and procedures, although the overall objective goes beyond the current state-of-the-art. This being so, the performance specifications should not be too extravagant.

It also seems that small-scale equipment is envisaged. Certainly equipment and procedures are not intended to be on the scale that is

typical for submarine pipe burying in the oil and gas industry. Nor is the work meant to be on the scale of cable burying operations for Atlantic telephone cables. This is another reason for holding the performance specifications within modest limits.

Another thing to keep in mind is that continuous machine trenching or cable-burying on dry land is subject to definite limitations. It is certainly not practical in hard rock.

It seems probable that this project is an attempt to respond to an existing practical need. However, the specifications appear to have been drafted to cover not only the immediate requirements, but also some hazy future contingencies (pipe as well as cable; diameters from 4 to 18 inches; all conceivable bottom materials). It might be advisable to design the prototype to meet present needs only.

In drawing up final specifications, it seems important to ensure that they are: (1) realistic and attainable, (2) internally consistent, (3) relevant.

As a final point, the emphasis on application of MIL-SPECS might be questioned for a prototype development of this kind. MIL-SPECS are not universally admired, and they could be inhibiting in a pioneering project that has to utilize off-the-shelf components and sub-systems.

Review of "Trencher" Performance Requirements

The following comments refer directly to Part III of the NAVFAC Statement of Work dated 3 September 1976.

III A 1a. Water depths. The depth range given is 0 to 150 feet. Criteria for selection of the 150-foot limit are not known to us, but the value seems reasonable. It permits use of Scuba divers, and it may be a realistic limit for ice scouring in northern waters. However, a datum elevation should be given. Is the depth referred to high tide level, low tide level, or mean sea level? The differences are certainly significant in areas such as northern Maine.

III A 1b. Tethered length at full power. A full power tethered length of 2500 feet is given. Taken in conjunction with the Operating Scenario of Part II, this implies that the trencher is not required to work more than 2500 feet from high water line. There are some beaches and bays where the horizontal distance between high and low water lines exceeds 2500 feet. During preliminary discussions it was suggested that the trencher might be required to work up to 2 miles out from the shore (see also expected beach slopes). A power transmission distance of 2500 ft could be a problem. It is about the practical limit for electrical transmission, and it almost certainly rules out direct transmission of hydraulic power. This figure should be reviewed, and the Operating Scenario of Part II should also be reconsidered.

III A 1c. Trencher cut depth. This is given as 0 to 7 feet, which provides a cover of 2 metres depth for the cable sizes given. In current pipe-burying plans, trenching to about 2 metres depth seems to be a common requirement. However, this trench depth is based on a requirement for 1 metre of cover. A cover of 1 metre also seems to be regarded as adequate for protecting telephone cables against the common hazards (dragging anchors, trawl boards). By contrast, in areas subject to ice scouring, 1 metre would probably give only minimal protection. It might also be inadequate in the loose bottom of a longshore trough that migrates seasonally. The difference between providing 1 m. of cover and 2 m. of cover is highly significant in terms of machine design. For example, power requirements and force levels differ by almost a factor of 2 for the two cases. As another example, a disc cutter could be used to cut to 1 m. or so, but it would be awkward to use a disc for cutting to 2 m. depth. This requirement should be considered rather carefully, and perhaps keyed to material type (shallower trench may be acceptable in hard materials, or in areas where ice scouring does not occur). Variable trenching depth has some influence on design.

III A1d. Trencher cut width. This is given as 4 to 18 inches. Part II gives a maximum diameter of cable or pipe as 6 inches (on page 2). All other things being equal, power requirements and force levels are almost directly proportional to trench width for many

systems. If a capability to cut 18-inch wide trench is not required in the planned operations, it might be advisable to adopt a value that is compatible with the cable sizes. The stated lower limit of trench width, 4 inches, is extremely narrow for a 7-foot deep trench, and it is close to the limit of what is feasible structurally in mechanical cutting systems. Trenching systems that excavate before pipe is laid have to make allowance for sideslope angles in soft materials, so that very wide trenches might have to be cut. This specification ought to be reconsidered to ensure that it is not unnecessarily restrictive. The specification itself might be redundant, since the objective is to bury cable rather than to produce trenches of specified dimensions.

III A 1e. This item seems to call for a capability either cut open trench or underrrun a line that has already been laid. However, it is not completely clear, and could perhaps be interpreted as calling for capability to do both things -- cut open trench and underrun cable/pipe. Whatever the intent, this specification seems to confuse the issue. To cut open trench 6 inches wide and 7 feet deep in beach sand is quite a trick. There is a good chance that the most desirable system will cut and lay simultaneously so as to avoid the problem of wall stability in open trench. This specification should be reconsidered.

III A 1f. This states that no backfill is required. This seems reasonable from a protection standpoint, but the cable or pipe might need ballast to hold it in place. A capability for partial backfilling could probably be provided without much trouble.

III A 1g. This item states that a jet or suction system is required to remove sand and loose debris. This may, or may not, be true. The goal is to bury cables and pipes, not to make clean open trenches. There are burial systems that do not use jets or suction. This specification should be deleted, since it imposes arbitrary design conditions.

III A 1h. Embedment speed. A minimum embedment speed of 0.5 linear feet per minute is called for. As a design goal, this seems too modest (a big drop from the 1 ft/sec asked for in early discussions on arctic seabed trenchers). We would suggest 2 ft/min as the minimum embedment speeds in hard bed materials. Higher speeds, say 6 ft/min, could be called for in soft materials.

III A 1i. This item calls for corrosion protection, without defining the requiremnt. A loose stipulation is probably appropriate here, as it will have to be a "best effort". However, III A 3b requires that the machine stay underwater for 10 days in an inoperative state, implying that there should be no detrimental corrosion in this period. This could be a troublesome spec.

III A 2 - Crawler Operations. This subsection is based on pre-judgment and pre-selection. The machine need not be a crawler. It could be a sled, a vehicle with wheels or rollers, a fluid cushion vehicle, a free floating vessel, or even a walking machine. The subsection should be re-title "Vehicle Operations".

III A 2a. Water depths. See comments on III A 1a.

III A 2b. Tethered length. See comments on III A 1b.

III A 2c. Speed of advance. This is given as 0-5 ft/min on level terrain. Presumably the intent is to specify a rate of movement for maneuvering the vehicle on the beach and for traveling to or from the start or finish of work. This is not a restrictive specification, but again it implies pre-selection. For example, it might be desirable to move the vehicle to or from an offshore point by floating on the surface. This spec isn't going to hurt (we can move almost anything at 5 ft/min), but it isn't much help. For transiting, we could easily ask for a speed 10 times higher, and even 150 ft/min isn't a great challenge.

III A 3a. Water depth for submerged shutdown. See comment on III A 1a.

III A 3b. This simply requires that the machine should be capable of staying underwater for up to 10 days without power. Words should be added to make the requirement more explicit -- to the effect that the machine should remain undamaged and capable of re-start. Perhaps this spec. should be linked with the corrosion specs. of III A 1i and III A 3e.

III A 3c. This calls for a capability to disconnect and re-connect umbilicals and tethers in water depths to 150 ft, using divers. There should be no great problem here, but thought should be given to the possibility that the cable/pipe might have to be broken and spliced under some circumstances.

III A 3d. The provision for ballasting called for here should not create any great problems.

III A 3e. Corrosion protection. See comments in III A 1i and III A 3b.

III B. Environment. This subsection is concerned with the environment in which an underwater trencher will operate. However, it ought to consider surface support operations as well.

III B 1a. Water temperature. The required operating range seems to run between the world extremes of water temperature. The lower limit will cause problems, as it could be associated with very low air temperatures, spray icing on the surface or the beach, or a wide variety of sea ice conditions. It is unreasonable to expect routine operation under these condtions. With weak sea ice or pack ice, surface support operations become difficult. On the beach and in the surf zone, the machine may be subject to icing. Diving operations are difficult (entry/exit problems, regulator freezeup, body chill, lack of light). This specification requires more attention.

III B 1b. Water currents. The machine is to be unaffected by currents up to 0.8 ft/sec from any direction. This specification may be adequate for work from open beaches, but the figure is probably too low to cover work in estuaries, tidal rips, bars, etc, where currents might be up to 8 ft/sec or more. It might be prudent to raise this value to 2 or 3 ft/sec, without necessarily making current velocity additive to wave particle velocity.

III B 1c. Breaking wave height. Operation in the range 1 to 4 feet seems a realistic goal. It may be worth noting that operation will normally be in a direction that is approximately at right angles to the wave crests.

III B 1d. Water depth. See comment under III A 1a.

III B 1e. Deep water wave height. The range 0 to 5 feet sounds reasonable for underwater operations. However, with steep short seas and 5-foot waves, a small surface support platform could begin having difficulties. This spec. ought to be linked with the spec. on wave period, III B 1f.

III B 1f. Deep water wave period. Taken alone, this spec. of 1 to 30 sec. just gives the frequency of pressure or force pulsations. It probably should be linked with the wave height spec., III B 1e.

III B 1g. Shoaling coefficient. The range for shoaling coefficient is given as 0.98 to 1.1. Presumably this helps to characterize beach conditions, but it is not clear to us how it affects the design and operation of a cable-burying system. It could be equally puzzling to a machine manufacturer, so some explanation would be helpful.

III B 2a. Beach slope. The range 1:200 to 1:50 should probably be given as a typical range (some areas will have zero slope). This is the only spec that mentions slopes. There should probably be another spec dealing with slopes and sideslope operation.

III B 2b. Minimum static and dynamic bearing capacity of bottom. The stated values of 200 lb/ft^2 and 100 lb/ft^2 should be checked. Low ground pressure vehicles usually exert higher bearing pressures than either of these values. For travel over very soft bottom, buoyancy tanks might be required. For tracked vehicles, the lowest practical value for nominal bearing pressure is about 150 lb/ft^2; with lower pressures and very weak ground, steering becomes awkward and intermittent immobilization is possible. Very wide tracks increase motion resistance, while very long tracks become unsteerable.

III B 2c. Bottom terrain with open trench. The vehicle has to be able to cross a trench 5 feet wide and 3 feet deep. Presumably it is allowed to cross at right angles. This sets some limits to vehicle dimensions and to weight distribution. With the center of gravity over the mid-section of fairly rigid tracks, the track length would have to be at least 12 feet. With more flexible tracks or more compliant suspension, the length would probably have to be at least 15 feet. This spec. should be checked to see whether it is necessary and realistic.

III B 2d. Bottom terrain obstacles. The vehicle has to be able to negotiate an obstacle that is 1 foot high. The specification does not state whether this obstacle is a step, a sill, or a block.

This should be clarified, as it might affect ground clearance requirements or suspension design. It should also be noted that Part II envisages operation along tracks that are "....cleared (to within the operation limits) .....".

III B 3. Bottom conditions for trenching. This subsection is presumably intended to specify the bottom conditions in which the system has to operate. Actually, it digresses into suggestions for machine design, and finishes with an unsystematic list of materials covering every conceivable bottom condition. III B 3 should be rewritten so as to specify the materials in which cable has to be laid. In doing this, technical feasibility for a "state-of-the art" procurement has to be kept in mind.

First of all, the machine has to be capable of burying cable in fine-grained non-cohesive soils, since these are common beach and bed materials. It should also be capable of operating in cohesive soils, such as stiff clays. This takes the specification to the limit of existing operational technology. Some mention should than be made of coarse gravels, and sediments that contain isolated cobbles and boulders -- these are acknowledged to be difficult materials, and probably at the limit of existing technology. The requirement for cutting some of the weaker rock materials should next be outlined. This list could include coral, some bonded submarine permafrost (silt, sand, fine gravel), some shales,

deteriorated rocks, some slate, etc. The desirability of extending capabilities to sandstone and limestone could also be noted. Finally, there should be explicit recognition that the machine will not be expected to trench in igneous rocks or the harder metamorphic and sedimentary rocks. Without the latter statement, the specification will lack credibility. Several people working in ocean engineering have stated unequivocally that continuous burial in hard bottom is not feasible. It is also a fact that on dry land it is not practically feasible to continuously cut trenches in anything but soils and very weak rocks.

In the final specifications, material type might have to be referred to some kind of engineering classification of rocks. Some notes on rock classifications for engineering purposes are attached to this report.

III B 4a. Air temperatures. This spec. requires that the underwater trencher shall be capable of operation with air temperatures from -60°F to +120°F. Air temperature has no direct effect on the underwater part of the operation, but it has a lot to do with operations on the surface. The upper limit of the given range sounds a bit unrealistic for air temperature over the sea or beach. The lower limit of the stated range is completely unrealistic for routine operation. Working of men or machines at temperatures below -40°F is very inefficient, and it often results in negative

progress. If there is a wind, temperatures higher than -40°F can still produce intolerable working conditions. If the spec. relates to removal of heat from men or machines, a wind chill factor should be introduced. With very low air temperatures it is unlikely that the surface of the sea will be unfrozen, and sea ice creates a very different situation, as mentioned already under III B 1a. Military equipment specifications frequently give absurd lower limits, but we don't have to follow this tradition.

III C 1. Training. The point to stress is that operating crews need training and experience for what is highly specialized work. The work "evolutions," mis-spelled two times out of three, seems to be Navy jargon, and it clouds the meaning a bit.

III C 2. Operator controls. It might be as well to specify that all functions should have both remote control and local control. A requirement for night operation sneaks in here. If night operation is required, a separate specification should be made to that effect.

III D 1. Logistic Support in Operation and Repair.

III D 1a. Consumables. It is not clear whether the 30-day supply is for laying a single cable or several cables. Nor it it clear

whether the supply has to sustain 30 working days of actual operation (e.g. 300 machine hours for 30 x 10-hour days). Heavy consumables will be the cable itself, fuels and lubricants, cutter replacements for a mechanical system.

III D 1b. Repair capability. This sounds reasonable.

III D 1c. Time between failures. When a mechanical cutter is working in hard and abrasive materials, cutting teeth will fail or wear out in much less than 72 hours of operation.

III D 1d. Repair time. The allowance of 6 hours for field repair seems reasonable, but further allowance is needed if the machine has to be taken to the surface or returned to the beach.

III D 1e. Preventative maintenance. P.M. at 12-hour intervals seems satisfactory for surface support equipment. However, a P.M. interval of 72 operating hours for the underwater unit may be far too long. With a mechanical cutter, teeth should probably be checked and serviced every 4 hours or so when working in hard material. With intermittent submersion, frequent washing and flushing might be necessary.

III D 1f. Overhaul. This specification needs clarifying -- the nature of the 1000-hour and 10,000-hour overhauls should be

defined. There should be provision for inspections at more frequent intervals -- say 100-hours for the underwater unit. For a mechanical cutting system, the entire cutting element might have to be treated as a consumable or a replacement item (to be serviced back at the depot).

III D 2. Storage. The equipment should be designed for unattended storage after cleaning, application of corrosion protection, re-lubrication, etc.

III D 3. Handling/Transportation. This item requires that the equipment should be transportable by C-141 or larger aircraft, or else by trucks on the road. The cargo bay of the C-141 is 123 inches wide, so that system modules could be almost 10 feet wide. However, for road transport 8 feet is the maximum width that can be moved without special permits. The latter is not a serious restriction, as loads to 12 feet wide are frequently hauled on the highway, but the width limit needs to be given explicitly. Are we bound to 8 ft or 10 ft? For the final spec., actual dimensions for weight and cube should be given, so as to save bidders the trouble of checking on military vehicles and military aircraft.

General Comments

The required system has to rely on existing technology; it

is intended to be a "state-of-the-art" procurement. In reality, existing technical capabilities do not permit burial of cable or pipe in hard bottom without recourse to drilling and blasting. This should be kept in mind when preparing specifications. The system should not be expected to trench continuously in very hard rock, as this is well beyond the capabilities of dry land systems. In the first instance, it should not be thought of as a system capable of laying and burying everything from 1-inch cable to 18-inch pipe. Burial depth should not be over specified, for example by calling for 7-ft depth in hard bottom when 4 ft would be sufficient.

Another danger is that the specifications could become too demanding by requiring operation in the most severe arctic environments. Presence of sea ice produces a radical change of operating environment. If cables have to be buried in arctic waters, the work should be done in summer for a start.

The Operating Scenario and the Performance Requirements imply a certain amount of pre-judgment and pre-selection as regards equipment and operating procedures. It is assumed for the present that this is not intended as a restriction on the scope of the study.

In section III, some mention of <u>tidal</u> <u>range</u> should be made, and possibly of tide frequency (certain areas have 4 "tides" a day).

Another matter that needs attention is burial on the beach above high water mark. This could be treated as a separate phase of the work, utilizing conventional methods (backhoe, drill and blast, conduits). It might turn out that it is neither necessary nor desirable to operate submarine equipment (e.g. submersible electric motors) in air.

Under III D 1, some methon of de-mobilization procedure might be added.

tension, which are special cases of the triaxial test, are by far the most common and widespread direct tests for rock properties.

Although enormous use has been made of uniaxial tests, and despite many attempts to clarify the controlling factors, there are still no generally accepted standards for equipment and technique. Consequently, it is difficult to make meaningful comparison of results obtained in different laboratories. In the related field of concrete testing, for example, SIGVALDASON (1964) gives evidence that the results of uniaxial compression tests on identical specimens made in eight different laboratories had wide discrepancies of magnitude and variance, even though all tests were made on machines conforming to the appropriate British Standards and A.S.T.M. standards.

Standardization is clearly desirable, but it should be based on a thorough understanding of the behaviour of the test material and of the detailed mechanics of the test. The test should also be designed to yield information which can be applied to research and engineering problems through the medium of theoretical concepts of deformation and fracture. In spite of the need, premature standardization would be inadvisable; improper standards would lead to confusion, and enforced conformity would inhibit development of sound technique.

For many years some shortcomings of typical test techniques have been recognized, and there have been numerous studies on particular aspects of test technique. These studies have highlighted certain problems, but they have not been fully successful in dispelling controversy. It now appears that interaction of some of the complicating factors necessitates a broader approach and an overall critical review embracing the composition, condition, and preparation of the test material, the theoretical background of testing, and the detailed mechanics of the test. The following review, which includes original contributions, is offered as a contribution to the reevaluation of uniaxial testing in rock mechanics.

TEST MATERIALS

Description and classification of rocks

Rocks. The term "rock" may embrace almost all solid earth materials. There is often no clear demarcation between "rocks" and "soils", and in rock mechanics any naturally occurring earth material which has sufficient cohesion to enable it to be loaded uniaxially can be considered rock. There are many ways of classifying rocks, but most are based primarily on geological origin or chemical composition, and are not generally suitable for engineering purposes, where the emphasis is on mechanical properties.

HANDIN (1966) has suggested that it is possible to categorize rocks on the basis of their mechanical properties, as follows: (*1*) the unfoliated igneous and metamorphic rocks and silica-cemented sandstone; (*2*) schist, slate and highly

by uniaxial compressive tests on small samples (diameter 1.5–4 inches, length/diameter 2.0–2.5)[1]. The tangent modulus at 50% of the ultimate stress is plotted against uniaxial strength on the classification chart shown in Fig.1. The rock is then assigned a two-letter designation, the first letter (A, B, C, D, or E) giving the strength category and the second letter (H, M, or L) giving the "modulus ratio", i.e., the ratio of modulus to strength. The numerical limits of the categories are given in Table I.

TABLE I

ENGINEERING CLASSIFICATION FOR INTACT ROCK
(After DEERE and MILLER, 1966; DEERE, 1966)

1. *Strength classification*

Uniaxial compressive strength (lbf/sq.inch)	*Description*	*Designation*
over 32,000	very high strength	A
16,000–32,000	high strength	B
8,000–16,000	medium strength	C
4,000–8,000	low strength	D
under 4,000	very low strength	E

2. *Modulus ratio classification*

Modulus ratio	*Description*	*Designation*
over 500	high modulus ratio	H
200–500	average modulus ratio	M
under 200	low modulus ratio	L

DEERE (1966) also makes two suggestions for quantifying the description of massive rock, one based on core recovery percentages in drilling operations, the other based on the ratio of field seismic velocity to sonic velocity measured on intact laboratory specimens.

A classification scheme for use in rock mechanics was proposed by COATES (1964), and was later modified (COATES and PARSONS, 1966). The Coates scheme, embodying the 1966 modifications, is given in Table II.

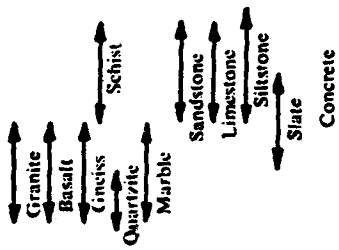
Items 4 and 5 of Table II were criticised by BURTON (1965) who suggested replacements (see note below Table II). These suggested changes were not adopted by Coates.

[1] See Appendix 4 for notes on units.

TABLE III

CLASSIFICATION OF ROCK MATERIALS BASED ON UNCONFINED COMPRESSIVE STRENGTH[1]
(After STAPLEDON, 1968)

Range of U.C.S. (dry samples[2])				*Range of strength of some common rock materials*
Term	*abbreviation*	*lbf/sq.inch*	*kgf/cm²*	
very weak[3]	VW	< 1,000	< 70	
weak	W	1,000–3,000	70–200	
medium strong	MS	3,000–10,000	200–700	
strong	S	10,000–20,000	700–1,400	
very strong	VS	> 20,000	> 1,400	



[1] Samples of fresh rock material tested to Australian Standards. For rocks showing planar anisotropy, the long axis of the samples is normal to the fabric planes.
[2] To be defined.
[3] Some overlap in strength with very strong cohesive soils, e.g., hard dessicated clays. The distinction can be made usually by soaking in water, when soils can be remoulded.

Factors influencing strength and deformability

The mechanical properties of a rock depend on its intrinsic composition and structure, and also upon the condition it is in when tested (e.g., temperature, water content).

In reviewing the characteristics which influence mechanical behaviour, it is helpful to work progressively from the scale of the single crystal to that of the rock mass (FRIEDMAN, 1967a). The properties of a single crystal are determined by its chemical composition, by the lattice structure (which determines glide systems), and by lattice defects such as vacancies and dislocations. The deformational behaviour of the crystal also depends on its orientation relative to the applied stress field and on the mode of load application.

In bulk specimens of intact rock the mechanical properties depend not only on the properties of the individual crystals, but also upon the way in which the crystals are assembled. The relevant information is given by a full petrographic description, which includes the mineralogical composition of crystals, grains, cementing materials and alteration products and also the grain structure and texture, including size, shape, distribution and orientation of crystals, grains, pores and cracks. The degree of isotropy, or anisotropy, is important, since mechanical properties are only scalar for isotropic material. Primary anisotropy, brought about by preferential orientation during crystallization, or by recrystallization during sedimentation or metamorphic processes, may be distinguished from secondary anisotropy, brought about by geologic deformation of the rock (FRIEDMAN, 1967a).

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